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Tevatron Proposal

A Search for New Massive States Decaying into $\phi^o\phi^o(n\pi)$, $\Lambda\overline{\Lambda}(n\pi)$, and $K_s^oK_s^o(n\pi)$

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Tevatron Proposal

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I. Summary

We propose to use a 1000 GeV proton beam incident on an upgraded Fermilab Multiparticle Spectrometer (MPS) Facility to search for new massive states decaying into $\phi^o\phi^o$, $\Lambda^o\overline{\Lambda}^o$, and $K_s^oK_s^o$, and $\phi\psi$ final states. The $\phi^o\phi^o$ and $K_s^oK_s^o$ systems select quark-antiquark states of C = + 1 which are not directly accessible to dilepton experiments. The reactions we wish to study are:

$$pp \rightarrow \Lambda^o\overline{\Lambda}^o(n\pi) + X,$$

$$pp \rightarrow K_s^oK_s^o\ (n\pi) + X,$$

$$pp \rightarrow \phi^o\phi^o\ (n\pi) + X, \text{ and}$$

$$pp \rightarrow \phi\ \psi\ (n\pi) + X.$$

The signal-to-background will be enhanced by triggering on the unique topological and kinematic features of the $p\pi^-$, $\pi^+\pi^-$, and K^+K^- decays of the Λ, K_s^o, and ϕ^o s, respectively. Final states containing muons will be identified by an additional muon detector which we plan to build.

The MPS aperture is large enough to provide good geometric efficiency for masses up to 10 GeV/c^2 in the region near $y^* = 0$ where heavy particle production is expected to be concentrated. Hence we wish to exploit the expected dramatic rise in the production cross section of heavy states provided by the available Tevatron energies. We request 1000 hours total Tevatron time, which includes both testing and data-taking time.

II. Physics Motivation

One of the most effective ways to find and study resonances in hadron interactions has been to probe a definite quantum state, such as using e^+e^- or $\mu^+\mu^-$ to study the $J^P = 1^-$ mesons $\rho, \omega, \phi, J/\psi, \psi'$, and Υ. The J/ψ and Υ were discovered using this technique. However, dilepton resonances are restricted to the $J^P = 1^-$ system.

We propose to use dihadrons with restricted spin and parity possibilities to examine other quantum states such as 0^+, 0^-, and 2^+. This proposal will expand our search for high-mass states extending beyond the energy limits and statistics of E580 and E623 using 1000 GeV protons from the Tevatron and the Fermilab MPS in the M6 beam line.

Some reactions and quantum states to be probed are:

Category I	I	J^P
$pp \to \phi^o\phi^o + X$	0	$0^-, 0^+, \ldots$
$\to \phi^o\phi^o\ (n\pi) + X$	0, 1, 2, ...	$0^-, 0^+, 1^-, 1^+, \ldots$
$\to \phi^o\psi + X$	0	$0^-, 0^+, 1^-, 1^+, \ldots$
$\to \phi^o\psi\ (n\pi) + X$	0, 1, 2, ...	$0^-, 0^+, 1^-, 1^+, \ldots$

Category II	I	J^P
$pp \to \Lambda^o\overline{\Lambda}^o + X$	0	$0^+, 0^-, \ldots$
$\to \Lambda^o\overline{\Lambda}^o\ (n\pi) + X$	0, 1, 2	$0^-, 0^+, 1^-, 1^+, \ldots$
$\to \Sigma^*\overline{\Lambda^o} + X$	1	$0^+, 1^+, 1^-, 2^-, \ldots$
$\to \Sigma^*\overline{\Lambda^o}\ (n\pi) + X$	0, 1, 2	$0^+, 0^-, 1^+, 1^-, \ldots$
$\to K^o_sK^o_s + X$	0, 1	$0^+, 2^+$
$\to K^o_sK^o_s\ (n\pi) + X$	0, 1, 2	$0^+, 0^-, 1^+, 1^-, \ldots$
$\to K^{o*}_sK^o_s + X$	0, 1	$0^-, 1^+, 1^-$
$\to K^o_sK^{*o}_s\ (n\pi) + X$	0, 1, 2	$0^+, 0^-, 1^+, 1^-, \ldots$

By probing these definite spin-parity states, new high mass resonances may be uncovered which can neither be produced directly in e^+e^- collisions nor detected in $\mu^+\mu^-$ or e^+e^- final states.

Although pion beams are being used for E580 and E623, we propose to use protons in this experiment in recognition of the probability that the early Tevatron pion beams may have too little flux at the highest energies. This point will be reconsidered at a later time when more information is available on pion flux intensities as a function of pion energy at high energies.

Our proposed study of Category I reactions is a resubmission of the Tevatron (phase II) portion of E623 with the important addition of dimuon triggers to search for the B^o ($b\bar{s}$) state. We propose a trigger scheme which utilizes the unusual topological features of ϕ^o decay; requiring the presence of a ϕ^o in the final state reduces the background by roughly a factor of 75.

We have measured the trigger cross section for a single ϕ^o with $p_\perp \geq 0.5$ GeV/c to be ~ 150 μbarns. In view of recent data on the $\phi^o\pi^{+-}$ mass spectrum, we will trigger on a single high $p_\perp$ ϕ^o. These triggers will be prescaled in order to match data rates with other triggers.

The $\phi^o\pi^{+-}$ system is an OZI forbidden final state for the strong decay of any quark-antiquark meson[1]. Thus the existence of a $\phi^o\pi^{+-}$ decay mode indicates either an OZI violating strong decay, a weak decay, or an allowed decay of a multiquark state (e.g. $qq\bar{q}\bar{q}$ states). Hence this trigger filter selects decays with very interesting physics with greatly improved signal-to-noise ratio.

The expected trigger cross section for two low mass K^+K^- pairs is about 6 μbarns. We will prescale this rate by a factor of 3 in order to study the low mass $\phi^o\phi^o$ system with adequate sensitivity. Since the $\phi^o\phi^o$ system has the smallest inclusive cross section of the decay products of glueballs, e.g. $\pi\pi$, KK, $\pi\rho$, KK^*, $\rho\rho$, K^*K^*,... We expect that the signal-to-noise ratio will be largest in this final state.

The trigger cross section for high $p_\perp$ states of $\phi^o\phi^o$ is expected to be about 2 microbarns for $p_\perp \gtrsim 0.6$ GeV/c (M $(\phi^o\phi^o) \gtrsim 2.4$ GeV/c). We plan not to prescale this trigger and thus emphasize high mass production. This will take maximum advantage of the Tevatron energy regime where the production cross sections of high mass objects are expected to rise dramatically.

The decay mode $\phi^o\phi^o$ is a filter for quark-antiquark states of C = +1 with q = s, c, b,... Such states are inaccessible to e^+e^- experiments directly. The sensitivity which can be achieved is comparable to that from the only previously published measurement.[2] A previous measurement[2] was made at low energy in an exclusive channel; we anticipate that we will be able to improve on this data sample by two orders of magnitude in our inclusive data at Tevatron energies.

The $\phi^o\phi^o$ final state yields information about the parity of the parent state η. Note that the $K^+ K^-$ decay plane tags the polarization direction of the ϕ^o, $\vec{\epsilon}$. The correlation between the two decay plane normals indicates the parent particle's parity. For a $\phi^o\phi^o$ state, the spin is 0, 1, or 2 i.e., $\vec{\epsilon}_1 \cdot \vec{\epsilon}_2$, $\vec{\epsilon}_1 \times \vec{\epsilon}_2$, or $(\epsilon_{1i}\epsilon_{2j} + \epsilon_{1j}\epsilon_{2i})$. The parity is $(-1)^\ell$. Boson statistics under exchange requires $\ell +$ s to be even. Hence for positive parity, s is even; for negative parity, s must be odd. This means that for positive parity the decay planes are preferentially parallel ($\vec{\epsilon}_1 \cdot \vec{\epsilon}_2$ or $\epsilon_{1i}\,\epsilon_{2j} + \epsilon_{1j}\,\epsilon_{2i}$), while for negative parity the decay planes are preferentially perpendicular ($\vec{\epsilon}_1 \times \vec{\epsilon}_2$).

The proposed study of Category II reactions is essentially an extension of E580 to Tevatron energies. However, we propose to enhance high-mass objects by utilizing a higher flux and a three-fold coincidence high level trigger. Since the Q-value for Λs is low, the decay protons carry most of the momentum of the Λ and point back to the production target. Thus the protons and antiprotons can be used in a fast trigger to estimate the $\Lambda\bar{\Lambda}$ effective mass. We are also investigating a scheme which will enhance the high mass $K_s^o K_s^o$ pairs by requiring that the charged particles which originate in the decay volume have a substantial opening angle.

Since vector mesons such as $\phi(s\bar{s})$, J/ψ $(c\bar{c})$, and $\Upsilon(b\bar{b})$ have narrow widths, they are not difficult to detect in the laboratory via their dilepton decay modes. It is important to note that the charm (c) quark can decay weakly to a strange quark (s), the beauty quark (b) can decay weakly to the charm quark (c), and the truth or top quark (t) can decay weakly to the bottom (b) quark. It is possible to use these decay modes in a search for: D^o $(c\bar{u})$ by detecting $\phi^o + K^o$; B^o $(b\bar{d})$ by detecting $J/\psi + D^o$; and T^o $(t\bar{u})$ by detecting $\Upsilon^o + B^o$. Since the J/ψ and Υ particles have a significant branching ratio for dilepton decays ($\sim 7\%$ and $\sim 2\%$, respectively), it is important to record dilepton information during our run. We have made some estimates of σB for D^o; the σB for the D^o could be as large as 10^{-33} cm^2.

The experimental layout for Category I reactions is shown in Figure 1. There is a general elongation of the E580 and E623 layouts due to: increased center of mass motion; an increase in the Cerenkov radiator due to the increased secondary particle momena; and a major MPS improvement envisioned with the addition of muon identification to the MPS apparatus. The experimental layout for Category II reactions is shown in Figure 2; a decay length region has been added between the target and the magnet

III. Theoretical Estimates and Other Experiments

The search for hadronic production of the η_c (2.97) has proven rather difficult. Standard techniques such as short lifetime detection and associated prompt muons are not useful. One needs a final state, analogous to $\psi \rightarrow \mu^+\mu^-$, with reasonable branching ratio and small combinatorial background. We have chosen the $\phi^o\phi^o$ final state which has C =+1. Measurement of the x and $p_\perp$ dependence of η_c production will determine whether the basic production mechanism is central or diffractive. As opposed to double arm spectrometer searches, our open geometry search can study the total event including target and projectile breakup. This capability should shed some light on the production dynamics.[2.]

Many estimates have been made for the production cross section.[3.] Most appear to favor $\sigma(\eta_c) \simeq 20$ microbarns in 1000 GeV/c pp interactions. In particular, the Halzen-Matsuda scaling using gluoproduction and CVC agrees with ϕ, ψ, and Υ production versus s over many decades of cross section. We expect that the estimate of $\sigma(\eta_c)$ is within a factor 2 of being correct. Various estimates are shown in Figure 3.

Several estimates of B ($\eta_c \rightarrow \phi\phi$) have also been made.[4] Most are within a factor of 2 of 0.1%. In addition, new data on B ($\chi \rightarrow \phi\phi$) have become available and agree with these estimates.[5] The estimate $\sigma(\eta_c)B(\eta_c \rightarrow \phi\phi) \simeq$ 20 nanobarns for 1000 GeV/c pp interactions is used in what follows. Note that this estimate is well above the 95% confidence limit values of 0.6 nanobarns for the $\phi^o\phi^o$ trigger.

The success of Halzen-Matsuda scaling gives us confidence in extrapolating to Tevatron energies. We assume a branching ratio for $\eta_b \rightarrow \phi\phi$ of 0.1%,[6] similar to that of the χ to obtain $\sigma(\eta_b)$ B $(\eta_b \rightarrow \phi\phi) = 32$ picobarns. We estimate we will have approximately 4 events on top of a negligible background in this mass region.

New experimental data have been reported. The Columbia/Fermilab/Stoney Brook data for $\phi^o\phi^o$ production have indeed confirmed that this spectrum is rather clean at high mass.[7]) In fact for a resolution of 20 MeV, the signal is estimated to be equal to the background if $\sigma(\eta_c) = 5.5$ microbarns or $\sigma(\eta_c)$ $B(\eta_c \rightarrow \phi^o\phi^o) = 5.5$ nanobarns.

The Fermilab/Johns Hopkins experiment has reported data on the $\gamma\gamma$ final state in 400 GeV/c pp collisions [8] . The signal to noise ratio is about unity within their mass resolution of 180 MeV for $\sigma(\eta_c) \simeq 70$ microbarns. A 95% confidence limit for $\sigma(\eta_c) \simeq 9$ microbarns has been reported.

These results make it clear that the $\phi^o\phi^o$ final state is more sensitive than the $\gamma\gamma$ final state since the mass resolution is better, the branching ratio is comparable, and the background is smaller (the $\pi^o\pi^o$ contamination of the $\gamma\gamma$ signal raises the background in this experiment). We expect to be able to measure $\sigma(\eta_c)$ at a sensitivity of roughly one order of magnitude better than the present 95% confidence limits.

Finally CERN's Ω proposal, P-136, was presented in January of 1980.[9] It is rather similar to its predecessor E623 except that the beam energy is 85 GeV which implies a factor of 10 reduction in $\sigma(\eta_c)$.

To compare experiments, E136 (CERN) requires only four kaons in the final state while E623 has the additional trigger requirement of low mass K^+K^- pairs (from ϕ^o decay) and a modest $p_\perp$ cut on the pair (enhancing high mass objects). We expect that our more restrictive trigger coupled with a larger production cross section at Tevatron energies will result in an experiment much more sensitive to the high mass region.

IV. Experimental layout

One expects that high-mass states are produced in pairs nearly at rest in the CM system (y^* near 0).[10] Thus it is important to have good geometrical acceptance for the kinematic region near $y^* = 0$. In addition, heavier states are produced with larger transverse momentum than pions; the two body-decay kinematics of heavy states contributes additional transverse momentum components. The large production and subsequent decay angles necessitate a large aperture system such as the MPS (see figures 1 and 2).

Most of the apparatus for this experiment already exists at the Fermilab MPS in the M6W beam.[11] The addition of drift chamber planes to replace the magnetostrictive spark chamber planes would convert the 10,000 PWC plus drift chamber system to a system with high data rate capabilities. Two finely segmented Cerenkov counters allow for unambiguous identification of kaon pairs.

1. Beam

We assume that the Tevatron will deliver 1000 GeV protons in a 20 second beam spill once per minute. The M6W beam will be set for positives at 1000 GeV/c and we will use existing beam line counters and PWC s. Beam intensity requirements for protons will be modest: listing a 15% active scintillation counter hodoscope as a production target, an intensity of 7×10^7 protons per spill (a rate of 3.3 MHz) with a $(5\text{mm})^2$ spot size will be adequate. With good primary intensities and favorable production cross sections for high energy pions, a decision to use a pion beam will be reserved for the future.

2. Upstream arm and MPS magnet

The MPS is described in reference[11]. Basically it is a 10,000 wire PWC system giving charged particle tracking for $\theta_x < 60$ mrad and $\theta_y < 40$ mrad with a transverse momentum kick of 650 MeV/c provided by a superconducting 48D48 magnet. A plan view of the apparatus is shown in Figures 1-2. The incident beam is tracked in two PWC modules which are not shown.

Small angle charged particles are detected first in the upstream arm of the MPS consisting of about 5,000 wires. The planes are x, x, u, v, y, y in A; x, x, x, x, y in B; and x, y, in C. Production angles are measured to an accuracy of ± .13 mrad in x and ± .17 mrad in y.

3. Downstream arm

The downstream (after the magnet) arm consists of another 5,000 PWC wires x, u, y, v, x, in D. At present these chambers are followed by 8 spark chamber modules and small PWC planes x, u, v, x (F). An upgrade now in progress for run E623 would allow higher beam rates and higher trigger rates. This upgrade entails the construction of eight planes of drift chambers x, u, v, x(EDR) and x, u, v, x (FDR). Outgoing angles will then be measured to a precision of .07 mrad in the bend plane. Momenta can then be derived to a precision of $\Delta p = \pm p^2 (3.3 \times 10^{-4} (\mathrm{GeV/c})^{-1})$.

4. Cerenkov counters

Mass identification of forward tracks is provided by two segmented Čerenkov counters, one with 44 cells ($\check{C}_A$) and one with 30 cells ($\check{C}_B$). $\check{C}_A$ will be filled with 1 atmosphere of nitrogen and $\check{C}_B$ with 1 atmosphere of neon. The pion thresholds will be 5.75 GeV/c and 12.2 GeV/c, respectively, while the kaon thresholds are 20.5 GeV/c and 43.4 GeV/c, respectively. These thresholds will be sensitive to the kinematics of central production.

5. Muon detector

The detection of muons is done conventinally using four meters of steel followed by a hodoscope of proportional tubes. The steel is 24 nuclear absorption lengths in the beam direction which will reduce the punch-through to acceptable levels. This depth of steel will weigh approximately 150 tons; it will stop muons with less than 5 GeV/c momenta (corresponding roughly to $x = 0$, $p_{\perp} \simeq 0.25$ GeV/c). Thus we will detect the entire forward hemisphere for muons.

The hodoscope will consist of 160 proportional tubes. Each tube will be 0.75 inches in diameter with a corresponding drift time of 200 nsec, which is comparable to that in the drift chamber cells. Data readout will be provided by attaching these to the MPS readout system of the PWCs. Finally, groups of five tubes will be "OR"-ed together to make a 32 element hodoscope input to the fast trigger processor.

V. Geometric Acceptance

Inclusive background was generated using the model of ref. 10 which incorporates the general features of inclusive production; $<p_t>$ increases with secondary mass, and production is more central as the secondary mass increases.

$$E \frac{d\sigma}{d\vec{p}} = A F(y^*) e^{-p_t}$$

where
$$F(y^*) = \frac{e^{-D/(y^*_{max} - y^*)^G}}{(M_t + B)^C},$$

$$M_t = \sqrt{p_t^2 + M^2}\ ,$$

A, B, C, D, and G are constants in the model and y^*_{max} is the maximum rapidity for a given M in the CM frame.

Background was assumed to be uncorrelated and all particles decayed isotropically. The geometric efficiencies for background were found to be: $\epsilon_K = 0.78$, $\epsilon_\pi = 0.62$, and $\epsilon_\phi = 0.72$.

VI. Description of triggers

1. Trigger processor

Previously the MPS has been triggered either externally using a calorimeter, or internally using the number of hit multiplicities in the PWC planes. We propose to expand the trigger capability of the MPS to encompass modern complex fast logic decisions as embodied in E623.[12] This processor will be used in the present proposal. The ingredients are three x-planes of PWC whose wires are "OR"-ed into a variable width 32 element fast stand-alone hodoscope and the $\check{C}_B$ Čerenkov hodoscope segmented into 30 cells. These cells are of varying size, with small cells in the middle, so as to match the density of charged tracks in the inclusive particle angular distribution. Initially the hodoscope data is latched in coincidence with a fast pretrigger requirement; the requirements $2_j \cdot \overline{\check{C}_{Bj}}$ are then imposed on the tracks. The Čerenkov counter $\check{C}_B$ will be filled with 1 atmosphere of neon in order to match the expected charged kaon momentum spectrum due to massive objects produced near $y^* = 0$.

The latched data are then used to form triple coincidence $1_i \cdot (2_j \cdot \overline{\check{C}_{Bj}}) \cdot 3_k$ combinations corresponding to tracks within the K^{+-} momentum window of $\check{C}_B$. Note that the triple coincidence has one level of redundancy, assuming that the tracks originate in a small target. The acceptable coincidences present their 1_i and 3_k addresses to memory look-up tables. These tables have incorporated the mass and $p_\perp$ of all tracks from interesting events.

Inelastic reactions will be selected by requiring an out-scatter from a beam veto counter located downstream of the MPS magnet. This essentially comprises the fast pretrigger. For a 3 MHz of proton rate incident on a 15% segmented active scintillator target, the inelastic interaction rate is 0.45 MHz. A trigger cross section of 5 microbarns corresponds to a trigger rate of 100 triggers per second. This data logging rate is near the maximum rate which the MPS system can effectively handle; it will be adjusted at run time to be at this maximum possible data taking rate.

The high level trigger has 2 microseconds to decide if the pretriggered event is interesting. The processor has been designed to perform all calculations in 250 nanoseconds; it will provide fast aborts in 100 nanoseconds, (for example, at least two charged kaons will be required to prevent a fast abort). This fast abort feature minimizes the dead time of the high level trigger processor.

2. Category I triggers

The test data taken for E623 indicate that the trigger rate for two low mass K^+K^- pairs is approximately 6 microbarns. Requiring $p_\perp$ of either $\phi^o > 0.8$ GeV/c ($M(\phi^o\phi^o) \geq 2.6$ GeV) reduces this rate to 0.8 microbarns. We propose to prescale the low mass $\phi^o\phi^o$ rate by a factor of ten to yield a trigger rate of 1.5 microbarns. We expect to reconstruct 720,000 $\phi\phi$s at low mass and 1.1×10^6 $\phi\phi$s at high mass in a 500 hour run.

Using E623 test data in the $\phi\phi$ mass spectrum and a measured mass resolution scaled to 1000 GeV production yields the 95% confidence limits for σB shown in Figure 3 for $\phi\phi$ and $\phi\phi$ at high $p_\perp$. The theoretical estimates are also shown in this figure from the B-G model[10] assuming a branching ratio, B, of 10^{-3}. The theoretical estimates for η_c and χ states also shown in the figure from the H-M model[3] establish that if glueballs are produced similarly to other hadrons, and have $\phi\phi$ branching ratio comparable to that of χ states, they will be seen. Note that the decay plane correlation of the $\phi\phi$ system will establish the parity of the glueballs. Note also that the η_c and χ states which are produced with cross sections comparable to theoretical estimates and measured branching ratios will also be seen.

3. Category II triggers

The triggers for $K_s^o K_s^o$ $(n\pi)$ and $\Lambda^o \bar{\Lambda}^o$ $(n\pi)$ will be similar to those used in E580. Added requirements will enhance high mass events which are expected to have greatly improved production cross sections at the Tevatron. The PWC s at the A-station measure the number of charged particles entering the decay region, n(the maximum n-value used in the E580 triggers was five). Following the decay region, the PWC s in the B, C, and D stations are required to have n + 4 charged tracks. The high level trigger will be similar to that described above for the category I case. The threefold coincidences will be used to identify protons and antiprotons which will then be used to make approximate measurements of the effective mass of the $\Lambda^o\bar{\Lambda}^o$ pair (the $K_s^o\Lambda^o$ and $K_s^o\bar{\Lambda}^o$ will be found by requiring at least one fast forward proton or antiproton).

The main point is that the decay angle of the proton from Λ^o decay (and the antiproton from $\bar{\Lambda}^o$ decay) is small and it carries off most of the Λ^o momentum. Even with the smearing of the decay points in the decay volume, the proton's (and antiproton's) position upstream and angle downstream yields an approximate measure of the $\Lambda\bar{\Lambda}$ mass with sufficient precision to remove the bulk of the cross section at low effective mass.

Based on a 500 hour run and on E580 data analysis, the 95% confidence limit of σB into $K^o_s\Lambda^o$ or $K^o_s\bar{\Lambda}^o$ are shown in Figure 4. Also shown are the expected rates for typical particles of narrow decay width and a 1% branching ratio. Clearly we can detect such particles if they are 4 GeV or lighter.

4. $\psi\phi$ triggers

During the $\phi^o\phi^o$ data taking we plan to include a high mass dimuon plus $\phi^o \rightarrow K^+K^-$ trigger. The purpose of this trigger is to investigate the possible decay of the B^o ($b\bar{s}$), $b \rightarrow cW^-$, $W^- \rightarrow \bar{c}s$ for $B^o \rightarrow \psi + \phi^o$. We will first require a low mass K^+K^- pair with $p_\perp \gtrsim 1$ GeV/c. Note that p^{cm} for $B^o \rightarrow \psi\phi$ is 1.7 GeV/c, so the $p_\perp$ requirement does not lose any real events. The initial trigger rate is approximately 50 μbarns based on E623 test data.

The muon hodoscope, Mu, will be wired into the E623 trigger processor with C_x and D_x so as to require at least one positive and one negative track with momentum $\geq$ 10 GeV/c. In an open geometry experiment such as the one we propose, the additional trigger requirements are dominated by the background of pion decays which will yield a 0.5 μbarn trigger rate, $\sigma(\phi^o \cdot \mu^+ \cdot \mu^-)$.

However the decay mesons preferentially yield low dimuon masses. We will use the trigger processor mass calculation to require a dimuon mass of $\gtrsim$ 1.5 GeV. This requirement will reduce the trigger rate to its final value of $\simeq$ 0.1 μbarns which is sufficiently low that including this trigger along with the main $\phi^o\phi^o$ data will add essentially no deadtime.

Using known ϕ^o production cross sections, dimuon backgrounds, and measured ϕ^o production data, one can estimate the $\psi\phi$ background to be $\sigma(\psi\phi)$ ~ 4 nbarns. Assuming a typical dihadron mass spectrum $d\sigma/dM = e^{-\alpha M}$ where $\alpha = 3\ (\mathrm{GeV})^{-1}$, the background within our mass resolution is approximately 5 picobarns at the 5.5 GeV mass region.

Assuming the $B^o(b\bar{s})$ is produced with a 100 nanobarn cross section at the Tevatron, and taking a 1% two body branching ratio, the effect would be $\sigma B \sim 35$ picobarns. Thus the signal to noise is quite good. Since the raw flux is 12 events per picobarn and the detection efficiency is estimated to be 5%, we expect 20 events on a background of 3. Although these statistics are limited, the signal to noise is excellant. If initial indications are faborable, one would contemplate using a higher beam flux and prescaling the $\phi\phi$ data triggers in order to further enhance these B^o $(b\tilde{s})$ events.

VII. Rates and Sensitivities

The experimental layout is shown in Figures 1-2. It is essentially the same as that of the original E623 proposal, but elongated to accommodate the increased CM motion at 1000 GeV/c. The apparatus has good detection efficiency for the central and forward production regions.

1. $\phi\phi$ Rates and η_c Detection

A detailed Monte Carlo program has been written to find the detection efficiency for χ states. The probability for all four kaons to be detected and fall within the Čerenkov momentum window is $\simeq 0.15$. This detection efficiency is rather flat for $p_\perp \chi \lesssim 2$ GeV/c. The efficiency peaks for $.05 \lesssim x_\chi \lesssim 0.2$ where the ψ production cross section peaks in $\pi^- p$ interactions. The layout has been designed assuming the production is central, and similar to that for the ψ[10].

Allowing for K decays, K interactions, ϕ K^+K^- branching ratios, and a limitation on the pion breakup charged multiplicity — 4 (scaling E580 data) our data cross section is 240 pb.

It should be emphasized that the trigger cross sections are based on test data taken during the E-580 run. Indeed, the trigger rates are higher than one might expect on the basis of a naive calculation.

First, the downstream multiplicity is required to be, $4 \leq N_f \leq 8$. This cross section is measured to be $\simeq 70\%$ of all non-diffractive inelastic interactions. Thus we are looking inclusively at η_c production. Based on our E-580 inclusive $K_s K_s$ data, $\simeq 70\%$ of all η_c will be accepted.

In addition, we require at least 4 tracks which satisfy hardwired

$C_{xi} \cdot D_{xj} \cdot FDR_{xk} \cdot \bar{\check{C}}_{Bj}$ coincidences. The allowed coincidences correspond to momenta, $12 \lesssim P_K \lesssim 43$ GeV/c, and no Čerenkov light. There must be at least 2 negatives and at least 2 positives. The cross section is measured to be $\simeq 80\,\mu b$. Note this is larger than one might estimate using $\langle n_K \rangle / \langle n \rangle \simeq 0.08$.

Since this rate is rather large, the trigger logic uses C_{xi} and FDR_{xk} to compute the K^+K^- effective mass in the bend plane (x, z), using a table lookup. The requirement of two low mass K^+K^- pairs reduces the trigger rate to 6.2 μb. Again, this rate is based on off-line analysis of P-623 test data. The reduction factor is rather less than $[\langle \phi \to K^+K^- \rangle / \langle K^+K^- \rangle \simeq .09]$[13] due to the loss of (y, z) plane information, and the finite resolution of $M_x(K^+K^-)$ due to the granularity of the trigger PWC hodoscopes.

Finally, a modest $p_\perp$ cut in the (x, z) plane is imposed. This cut is not biasing at the η_c mass. We observe a $p_\perp$ falloff similar to other data.[10] Note that the final trigger rate is reduced to 1.0 microbarns. This trigger rate is small enough so that a flux of 3×10^6/sec yields a moderate system dead time. The raw sensitivity is 12 events/pb for a 500-hour Category I run. We expect to detect approximately 2000 decays which is sufficient to study the production characteristics using the background inferred from E608. We expect a 95% confidence limit of $\sigma(\eta_c)\,B(\eta_c \to \phi\phi)$ of 0.6 nb as against the expected value of 2 nb.

Based on a 500 hour run, Monte Carlo runs for efficiency, and the mass spectrum in the E623 test data, the 95% confidence limits for this experiment, $\sigma B(\phi\phi)$, are shown in Figure 3. Also shown are the expected rates of typical narrow particles[3] with a 0.1% $\phi\phi$ branching ratio. Clearly glueballs with these typical production and decay characteristics would be detected. In addition, we show the prediction of a gluo production model[10] for η_c and χ using measured[5] branching ratios. Clearly these states will be observed in this experiment.

2. $\Lambda^o\bar{\Lambda}^o$, $K_s^o\Lambda^o$, $K_s^o\bar{\Lambda}^o$

The E580 2-V^o trigger rate at 200 GeV/c is 20 microbarns. By imposing the fast trigger processor requirements on the proton or antiproton, this trigger rate will be reduced to 9 microbarns. Further requirements on $p_\perp$ for the proton or antiproton will remove some of the low mass events which dominate the E580 data and will bring the trigger cross section to 5 microbarns. This requirement will thus enhance the high mass sensitivity and take maximum advantage of the increased production cross section for high mass states at Tevatron energies.

The total trigger rate for Category II triggers is expected to be 5 microbarns. This is comparable to the trigger rate for Category I triggers so the same comments on sensitivity apply here as well. Since E580 observes a mass spectrum falling as $d\sigma/dM = Ae^{-\alpha M}$ with $\alpha = 3\ \mathrm{GeV}^{-1}$, one can easily estimate sensitivities at a given mass knowing that $\gtrsim$ 3% of the triggers in E580 are reconstructable V^oV^o events.

We expect that in a 500 hour run we will obtain 560,000 $K^o\Lambda^o$ or $K^o\bar{\Lambda}^o$ events and 340,000 $\Lambda^o\bar{\Lambda}^o$ events. The σB 95% confidence limits for this experiment are shown in Figure 4; they are based on our E580 data trigger rates, trigger purity, dihadron mass spectrum and mass resolution scaled to 1000 GeV production energies.

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Figure Captions

Fig. 1 Experimental plan view for Category I reactions. T is an active segmented target of 20 scintillation counters which enables the z-value of the interaction to be measured. The PWC's are labelled: A which has measuring planes in views x, x, u, v, y, and y; B has views x, x, x, x, and y; C has views x and y; D has views x, u, y, v, and x; and F has views x, y, u, and v. Drift chambers EDR and FDR each has planes x, u, v, and x. Cerenkov counters $\check{C}_A$ is a 4 x 11 element hodoscope and $\check{C}_B$ is a 30 element hodoscope. Hadrons are filtered out in front of the muon hodoscope, Mu HOD, by 4 meters of iron, Fe. A "typical" event is superimposed on the drawing; the parent mass is 10 GeV which decays to $\phi\phi$ and each ϕ subsequently decays to K^+K^-.

Fig. 2 Experimental plan view for Category II reactions. The elements are labelled as in Figure 3. The spacing in the upstream arm is altered so as to provide a 4 meter decay volume for the neutral vees; this region is filled with a bag of helium so as to minimize neutral particle interactions in air. A "typical" event is superimposed on the drawing; the parent mass is 10 GeV which decays to a $\Lambda^o\bar{\Lambda}^o$ and the Λ^o ($\bar{\Lambda}^o$) decays into a $p\pi^-$ ($\bar{p}\pi^+$).

Fig. 3 σB values versus effective mass, M (GeV), where σ is the production cross section and B is the decay branching ratio to $\phi\phi$ states. The solid and dashed lines are the 95% confidence limits for $\phi\phi$ (all) and $\phi\phi$ (at high $p_{\perp}$), respectively, which can be measured by this experiment. The dot-dashed line is the predicted σB from the B-G model.[10] The circles are the preducted values of σB for η_c (~ 3 GeV) and for the three χ states (3.42, 3.51, and 3.55 GeV) from the H-M model[3]. B is assumed to be 0.001.

Fig. 4 σB values versus effective mass, M (GeV), where σ is the production cross section and B is the decay branching ratio. The solid and dashed lines are the 95% confidence limits for $(K_s^o\Lambda^o + K_s^o\bar{\Lambda}^o)$ and $\Lambda^o\bar{\Lambda}^o$, respectively, which can be reached by this experiment. The dot dashed line is the prediction of the B-G model[10]. B is assumed to be 0.01.

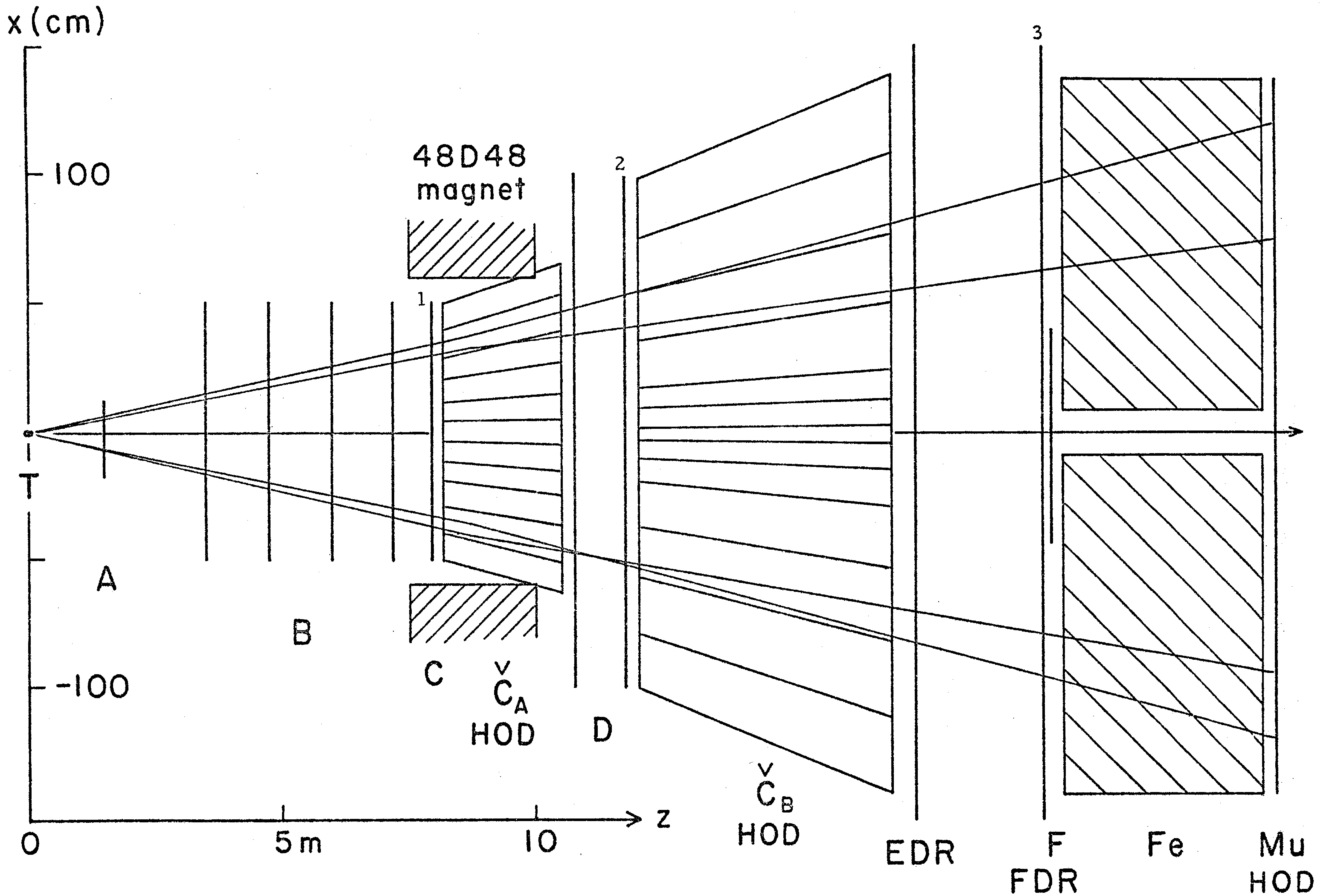

x (cm)
100
-100
T
A
B
48D48
magnet
1
2
3
C
Č_A
HOD
D
Č_B
HOD
EDR
F
FDR
Fe
Mu
HOD
0
5 m
10
z

Figure 1

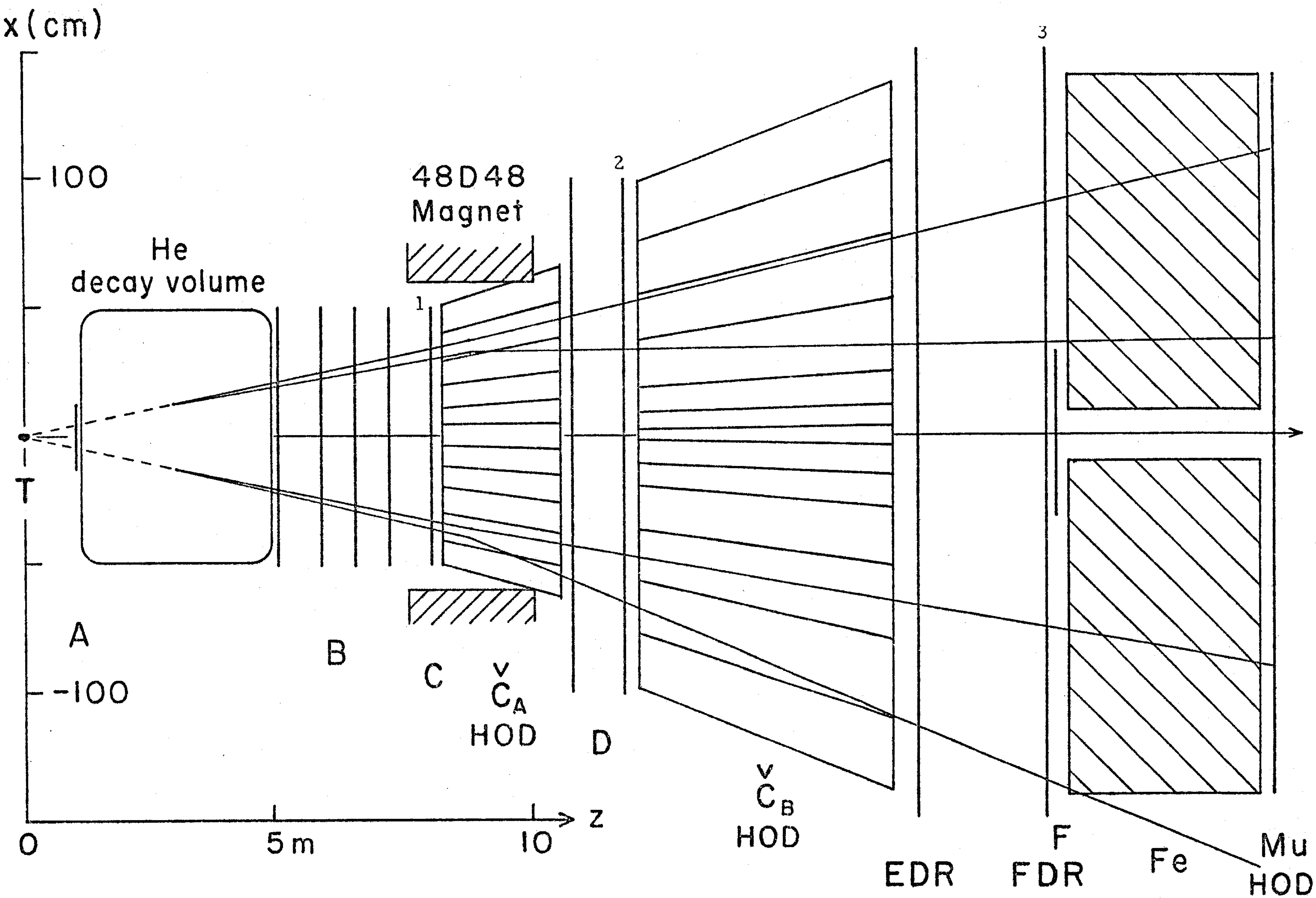
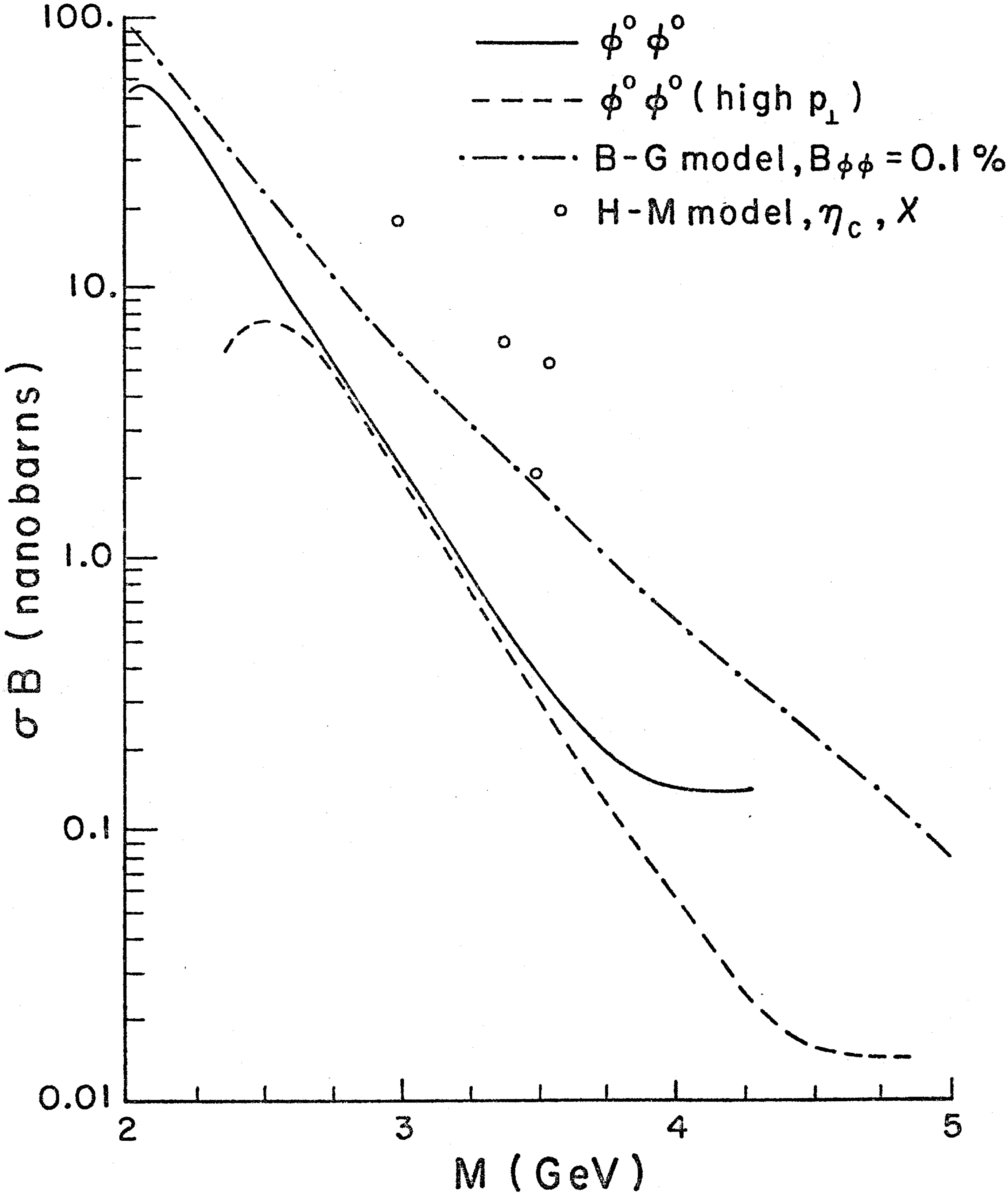
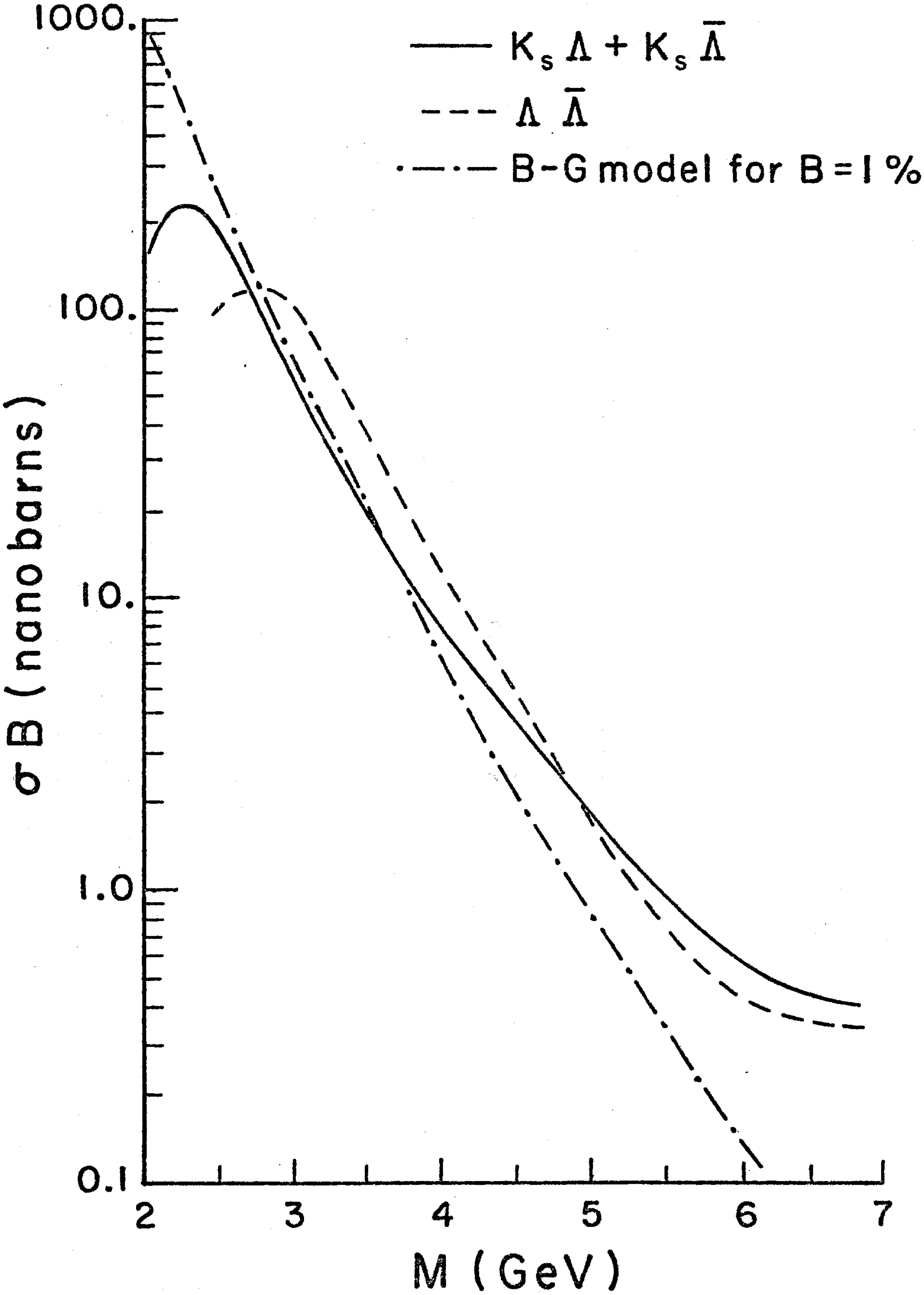

x (cm)
100
-100
T
A
He
decay volume
B
48D48
Magnet
1
C
Č_A
HOD
D
2
Č_B
HOD
EDR
3
F
FDR
Fe
Mu
HOD
0
5 m
10
z

Figure 2



100.
10.
1.0
0.1
0.01
2
3
4
5
M (GeV)
σ B (nanobarns)
φ° φ°
φ° φ° (high p⊥)
B-G model, Bφφ = 0.1 %
H-M model, ηc , χ

Figure 3



$K_s \Lambda + K_s \bar{\Lambda}$
$\Lambda \bar{\Lambda}$
B-G model for B = 1 %
1000.
100.
10.
1.0
0.1
2
3
4
5
6
7
σ B (nanobarns)
M (GeV)

Fig 4